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Kalibracija in točnost instrumentov za merjenje padavin brez njihovega zajemanja

Calibration and accuracy of non-catching precipitation measurement instruments

Kalibrierung und Genauigkeit von nicht auffangenden Niederschlagsmessgeräten

Étalonnage et précision des pluviomètres sans captage

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Calibration and accuracy of non-catching precipitation measurement instruments

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This Technical Report was approved by CEN on 8 October 2023. It has been drawn up by the Technical Committee CEN/TC 318.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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European foreword

This document (CEN/TR 17993:2023) has been prepared by Technical Committee CEN/TC 318 “Hydrometry”, the secretariat of which is held by BSI.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

The document was prepared following a request for research development submitted by CEN/TC 318 in October 2017 to EURAMET, the European Association of National Metrology Institutes, through the cooperation programme between STAIR (the joint CEN-CENELEC strategic Working Group supporting standardization in research and innovation) and EMPIR (the European Metrology Programme for Innovation and Research of EURAMET).

This led to the approval and funding of the EURAMET pre-normative project 18NRM-03 "INCIPIT - Calibration and accuracy of non-catching instruments to measure liquid/solid atmospheric precipitation" (2019-2021). The project Deliverable D1, "Overview of existing models and working principles of non-catching precipitation gauges together with test/calibration schemes for different types of non-catching precipitation gauges" was provided as a supporting document to CEN/TC 318 and is the basis of the present CEN/TR draft.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

Introduction

The development of highly accurate precipitation gauges for both liquid and solid precipitation is an increasingly relevant and pressing requirement in the environmental sciences and their applications (Lanza and Stagi, 2008). Non-catching instruments, which do not use a container to collect the hydrometeors when approaching the ground, are the emerging class of in-situ precipitation gauges (Cauteruccio et al., 2021). They detect the microphysical and dynamic characteristics of single or multiple hydrometeors while these cross a given section, or a volume, of the atmosphere (or directly impact the sensor) by employing optical, acoustic, and microwave principles.

National Meteorological and Hydrological Services (NMHS) and other organizations, in charge of the management of monitoring observation networks over large regions, increasingly look at such kind of instruments as a potential improvement over the more traditional catching-type gauges (typically tipping-bucket and weighing gauges), notwithstanding the higher lifecycle cost. The reasons are their potential in reducing the maintenance burden (by eliminating any moving part or containers to be periodically emptied and serviced), the high temporal resolution, the large number of parameters provided, and their suitability to be part of a fully automated monitoring observation network. Drawbacks can be easily identified in the higher complexity of the exploited technology, so that the capability of the user to correctly manipulate, maintain and calibrate the instrument might be limited.

Non-catching instruments are generally calibrated by the manufacturers, using internal procedures developed for the specific technology employed. No widely agreed procedure – nor any documentary standard – exists within national or international institutions. The adopted procedures are rarely traceable to the International System of Units (SI) and are often not even reproducible. Limited information is generally provided by the manufacturers about the methodology and instrumentation adopted for calibration purposes.

Having no funnel to collect the rainwater, traceable calibration and uncertainty evaluation for non-catching gauges are more difficult than for catching type gauges, and the use of an equivalent, reference flow rate (see e.g. Colli et al., 2014) is not possible. Rather, for an appropriate metrological characterization of non-catching instruments, reproducing the actual rain event characteristics is needed, including particle size distribution, shape, density and fall velocity. A considerable metrological effort is therefore needed to resolve traceability and uncertainty issues and to support new calibration methods including the development of standardized laboratory rainfall simulators.

As regards solid precipitation, non-catching instruments were included in the recent WMO SPICE (Solid Precipitation InterComparison Experiment) and compared with gauge measurements in a DFIR (Double Fence Intercomparison Reference) at various test sites (Nitu et al., 2018). The study concluded that further analysis is needed to better understand the behaviour of non-contact type measurement instruments, especially working with the raw data (drop size and fall speed distribution), and exploiting the full capacity of such devices, that can provide much more information than the precipitation accumulation (precipitation type, SYNOP and METAR codes, etc.). Field tests on SPICE reference sites have been continued in that sense after the official end of the project (Smith et al., 2020) to enhance the knowledge on the operational use of non-catching type instruments in winter conditions.

For liquid precipitation measurements, the evidence from the last WMO intercomparison of rainfall intensity gauges in the field (Vuerich et al, 2009) is that, due to calibration issues, caution should be posed in using the information obtained from non-catching instruments in any real-world application and in assessing the results of scientific investigations based on such measurements.

The main effort to develop standard procedures for the calibration of precipitation measurement instruments is presently being performed at the European level. The first experience was the development of the Italian national standard UNI 11452:2012, and the follow-up extension of such initiative at the European scale, leading to the publication of the recent standard EN 17277:2019. The scope of the standard is however limited to catching type gauges, which – due to the presence of the rain collector – can be calibrated using a known and constant flow rate generated in the laboratory as the reference (Santana et al., 2015). Traceable instrument calibration for non-catching gauges is the next step of the ongoing normative effort at the European scale under CEN/TC 318/WG12, but various scientific and methodological aspects are still open issues.

The project MeteoMet (Merlone et al., 2015), funded under the European Metrology Research Programme (EMRP), initiated a series of experimental activities in metrology for meteorology, with the MeteoMet2 specifically addressing the issue of atmospheric precipitation measurements from a metrological perspective. An associated research grant focused on rainfall measurements using catching and non-catching gauges. It is under this framework that, to support the ongoing normative effort, the INCIPIT project "Calibration and accuracy of non-catching instruments to measure liquid/solid atmospheric precipitation" was initiated in July 2019 (Merlone et al., 2020).

The project aimed at introducing metrological soundness, reproducibility, and standardization in the calibration of non-catching type instruments, so that an uncertainty budget can be determined, and measurements made traceable to the SI. A rigorous metrological approach based on modelling the measurement process and expressing the influence parameters in a model function was implemented, taking in account different types of rain-gauges and the different calibration schemes. By developing, characterizing, testing, and comparing different types of rain generators, test calibration of a representative number of different non-catching rain gauges was performed.

This document provides an overview of the existing models of non-catching instruments with a description of the working principle exploited and the calibration procedures currently adopted. The literature and technical manuals disclosed by manufactures are summarized and discussed. The report allows knowledge to be shared and provides consistent background information needed to advance the standardization activities towards the development of traceable procedures for the calibration of non-catching gauges and the associated calibration uncertainty assessment, as well as the evaluation of the accuracy of non-catching precipitation measurement instruments.

1 Scope

Non-catching type gauges are the emerging class of in situ precipitation measurement instruments. For these instruments, rigorous testing and calibration are more challenging than for traditional gauges. Hydrometeors' characteristics like particle size, shape, fall velocity and density need to be reproduced in a controlled environment to provide the reference precipitation, instead of the equivalent water flow used for catching-type gauges. They are generally calibrated by the manufacturers using internal procedures developed for the specific technology employed. No agreed methodology exists, and the adopted procedures are rarely traceable to internationally recognized standards. This document describes calibration and accuracy issues of non-catching instruments used for liquid/solid atmospheric precipitation measurement. An overview of the existing models of non-catching type instruments is included, together with an overview and a description of their working principles and the adopted calibration procedures. The literature and technical manuals disclosed by manufacturers are summarized and discussed, while current limitations and metrological requirements are identified.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

4 Main characteristics of atmospheric precipitation

4.1 Definitions

The World Meteorological Organization (WMO), in its Guide to Meteorological Instruments and Methods of Observation (WMO, 2014 updated 2017), defines atmospheric precipitation as "the liquid or solid products of the condensation of water vapour falling from clouds or deposited from air onto the ground".

Hydrometeors falling through the atmosphere can have different size, shape, velocity (magnitude and components) and density. The precipitation intensity (usually indicated as Snowfall Intensity – SI for solid and Rainfall Intensity – RI for liquid precipitation) and the associated Particle Size Distribution (PSD) are two main factors used to characterize a precipitation event. The precipitation intensity is defined by the WMO/CIMO guide as "the amount of precipitation collected per unit time interval" while the PSD, usually indicated with $N(d)$ and expressed in [L^{-3} L^{-1}], provides the number of particles (liquid or solid) per unit volume of air and unit size interval having a volume equal to the sphere of diameter d [L].

The most common types of rain are stratiform, that falls from nimbostratus, and convective that falls from cumulus and cumulonimbus.

Stratiform precipitation originates in high clouds, where small ice crystals are formed. In these clouds, the vertical wind is on average much smaller than the fall speed of the ice crystals, hence the wind cannot prevent them from falling. When they fall in a supersaturated air, they grow by vapor deposition. They can also grow by aggregation of ice particles. When the ice crystals reach an altitude where the air temperature (T) is above 0 °C they melt and can still grow by aggregation, but this phenomenon is of minor importance. This type of rain therefore tends to have small droplets (Rulfová and Kyselý, 2013).

In convective precipitations, the vertical wind is more important (1 m s^{-1} to 10 m s^{-1}) and can carry the growing particles upward until they become heavy enough to overcome the updraft and begin to fall to the ground. During this period where the droplets are suspended, they can grow by accretion of liquid water. Since there are strong upward winds, the small droplets cannot fall and the rain has on average larger droplets than in stratiform precipitations (Penide et al., 2013).

The text of Clause 4 is derived from the work of Cauteruccio (2020).

4.2 Particle size distribution

The PSD is usually depicted in a (d, N(d)) semi-logarithmic plot. A universal formulation for the PSD is not available since it is influenced by the regional and seasonal climatology governing the formation of hydrometeors in the atmosphere. Information about the PSD comes from observations. Physical properties of solid and liquid particles were derived in the past by employing raindrop spectrometers or radar sensors (see e.g. Waldvogel, 1974), while disdrometers are currently used to observe the size distribution characteristics of the precipitation process (see e.g. Caracciolo et al., 2008). Moreover, PSD measurements are affected by the limitation of disdrometers to detect small size particles, especially when d < 1 mm (Caracciolo et al. 2008).

Two formulations for the PSD are commonly used in the literature: the Exponential (Marshall and Palmer, 1948) – hereinafter MP – and the Gamma (Ulbrich, 1983) distributions. Marshall and Palmer (1948), by fitting experimental observations, provided the exponential form of the PSD as follows:

$$N(d) = N_0 \, e^{-\Lambda d} \quad [mm^{-1}\, m^{-3}] \tag{1}$$

where N_0 and Λ are two suitable parameters, with N_0 [mm^{-1} m^{-3}] the intercept and Λ the slope of the linear form of this curve in a semi-log plot.

Marshall and Palmer, for a widespread mid-latitude rain, found a constant value for N_0 (Formula (2)) and a relationship for Λ, as a function of the rainfall intensity (RI), as reported in Formula (3).

$$N_0 = 8\,000 \quad [mm^{-1}\, m^{-3}] \tag{2}$$

$$\Lambda = 41\, RI^{-0.21} \quad [cm^{-1}] \tag{3}$$

This distribution is valid for stratiform precipitations and has the tendency to overestimate the concentration of small droplets (typically under 0,5 mm). Indeed, these small droplets cannot fall in case of upward wind and tend to evaporate when they enter non-saturated air. Integration of this distribution between 0,5 mm and 6 mm for a rainfall rate of e.g. 5 mm h^{-1} gives a total concentration of droplets of $6{,}4\times10^{-4}$ [cm^{-3}]. This means that there are typically between 100 and 1 000 droplets/m^3 during stratiform rain, corresponding to an approximate distance between drops of 20 cm and 10 cm.

Waldvogel (1974), by measuring the distribution of raindrops with an electromechanical spectrometer and by means of a radar reflectivity analysis, for different types of precipitation (showers, thunderstorms, and widespread rain), showed that the parameter N_0 is not constant and changes abruptly. He called this phenomenon “The N_0 jump”. Radar measurements indicated that the N_0 jump occurred when one of the mesoscale convective areas moved in or out the region above the station, which means that the situation changed from uniform (widespread rain) to convective (shower or thunderstorm) or vice versa.

For very small drop diameters (below 1 mm) the *N(d)* values decrease with decreasing the particle diameter, therefore, a downward concavity of the PSD is obtained. Currently, it is not clear whether this characteristic is ascribable to the limitation of the measuring instruments to detect very small particles or it is physically based. Moreover, some disdrometers, especially radars, provide higher *N(d)* values for small diameters causing an upward concavity in the distribution.

Ulbrich (1983) proposed the Gamma distribution in the form:

$$N(D) = N_0\, D^{\mu}\, e^{-\Lambda D} \quad [mm^{-1}\, m^{-3}] \tag{4}$$

where the exponent μ is the shape parameter and can have positive or negative values and the intercept N_0 is in [$mm^{-1-\mu}\, m^{-3}$].

Ulbrich summarized experimental observations reported by other authors including Mueller (1965), Caton (1966) and Blanchard (1953). In the work of Mueller, a variety of rainfall types including continuous rain, showers and thunderstorms were observed and for all of them the observed PSDs are concave downward. When fitted with the gamma formulation these PSDs would have $\mu > 0$. Almost all Caton's PSDs are like those reported by Mueller and can be described by a Gamma distribution with $\mu > 0$. Differently, orographic precipitation, as observed by Blanchard, is characterized by numerous small size drops. This type of precipitation events can be described by a Gamma distribution with $\mu < 0$. In addition, Ulbrich conducted a theoretical analysis with the aim to describe the modification of the distribution from the exponential form to a concave shape. The author affirmed that the variation in N_0 is independent from the variation of Λ, while a direct relationship between N_0 and μ exists in the form:

$$N_0 = 6x10^4\, e^{3.2\mu} \quad [cm^{-1-\mu}\, m^{-3}] \tag{5}$$

Caracciolo et al. (2006) provided a discrimination algorithm to classify precipitation in convective or stratiform classes based on a large dataset covering about three years of observations (2001–2004) for about 1 900 min of rain, collected in Ferrara (northern Italy) using a Joss-Waldvogel (JW) disdrometer and supported by radar measurements.

First, both precipitation intensity (RI) and radar reflectivity (Z) were used for the classification into convective and stratiform precipitation as reported below:

RI < 10 mm h^{-1} and Z < 38 dBZ stratiform;

RI < 10 mm h^{-1} and Z > 38 dBZ convective;

RI > 10 mm h^{-1} convective.

Then, based on the PSD parameters the so-called peak (or modal) diameter D_p was defined as:

$$D_p = \mu\, \Lambda^{-1} \quad [mm] \tag{6}$$

Using this criterion, the stratiform spectra are characterized by lower D_p values with respect to the convective ones and the threshold between the two precipitation types is defined by the curve:

$$1{,}635\Lambda - \mu = 1 \tag{7}$$

The work of Caracciolo et al. (2008) is based on rain events measured in the Italian territory by employing radar and two different types of disdrometers (JW and Pludix) with a sampling time of one minute. Each one-minute PSD value was classified into one of six categories, based on the measured precipitation intensity (RI).

Both the exponential and Gamma formulations were used by the authors to provide new discrimination criteria between convective and stratiform precipitation according to radar reflectivity measurements. Using the JW data, a convective/stratiform discrimination criterion considering also shallow convective and heavy stratiform rain was developed:

RI < 10 mm h^{-1} and Z < 38 dBZ stratiform;

RI > 10 mm h^{-1} and Z < 38 dBZ heavy stratiform;